Swallowing Physiology
What clinicians need to know about peripheral and central nervous systems

Part 1 - Peripheral nervous system

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Physical Medicine and Rehabilitation
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Part 1 Outline
Terminology
Cranial Nerves and Muscle
Swallowing Anatomy & Physiology
Traditional Swallowing Treatment
Heightened Stimulation & Swallowing

Part 1 Outline
Terminology
Cranial Nerves and Muscle
Swallowing Anatomy & Physiology
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Terminology

Anatomy – The study of the structure of organisms and the relations of their parts

Physiology – A science dealing with the functions of living organisms or their parts

Terminology

Basic Anatomical Planes of Reference

Sagittal
Basic Anatomical Planes of Reference

Terminology

transverse

coronal

Physiology

The branch of biology that deals with the normal functions of living organisms and their parts; the way in which a living organism or a bodily part functions
Terminology

Pathophysiology
The study of the changes of abnormal mechanical, physiological, and biomechanical functions, either caused by a disease, damage, or resulting from an abnormal syndrome.

Terminology

Kinematics
The branch of mechanics that studies the motion of a body or a system of bodies without consideration of the forces acting upon it.

Terminology

Neuromuscular
Refers to both nerves and muscles. If a movement occurs due to neuromuscular control, then a motor (efferent) nerve has innervated a muscle causing it to contract or inhibited contraction causing the muscle to relax.
Terminology

Biomechanics
The study of the action of external and internal forces on the living body, especially the skeletal system

Terminology

Kinematics – movement

Biomechanics – movement and forces

Terminology

Rheology
The branch of physics that deals with the deformation and flow of matter
Terminology

**Rheology**
The branch of physics that deals with the deformation and flow of matter

**Bolus Flow!!!**

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Videofluoroscopy

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**Question for you:**
What do we definitely see on fluoro?

- anatomy
- physiology
- kinematics
- biomechanics
- rheology
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Why does terminology matter?

- Shows understanding of your area
- Encourages thinking about physiology
- Assists in understanding research
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Traditional Swallowing Treatment
Heightened Stimulation & Swallowing

Cranial (and Spinal) Nerves
Motor
• Innervate the muscles involved in swallowing
• Descent from nuclei in the brainstem (medulla, pons)

Sensory
• Send information from various sorts of sensory receptors up to the brainstem so that the brain is aware of what is happening in the oral cavity and pharynx

Cranial Nerves
CN V  → Trigeminal
CN VII → Facial
CN IX  → Glossopharyngeal
CN X   → Vagus
CN XII → Hypoglossal
GENERAL SENSORY
Cranial Nerve Innervation

CNV – anterior 2/3 tongue, palate
CNIX – posterior 1/3 tongue, palatal arches, upper pharynx, valleculae
CNX – lower pharynx, upper esophagus, intrinsic larynx, valleculae

Taste – CNVII anterior 2/3
CNIX posterior 1/3

Muscle

• The principal mediator of all of our movements
• Responsible for voluntary and involuntary movements
• Striated (skeletal), Smooth (visceral), Cardiac (heart)
• Innervated by the peripheral nervous system (PNS)
• ~329 skeletal muscles, most are paired
Striated Muscle

• Usually has two attachments: **Origin** and **Insertion** (embryonic development)

Muscle name is sometimes a composite of its origin and insertion points:

- **Thyrohyoid**: origin – oblique line of thyroid cartilage
  insertion – inferior border of hyoid bone body

• Muscle contraction shortens the distance between origin and insertion, so we can predict what a particular muscle contraction will do, however…………….\

Striated Muscle Disclaimer

Action in a living body is not a laboratory model of muscle activity. Muscles act in functional groups, so the lab model often doesn’t account for opposing or complementary muscles in the group.
What is striated muscle?
Skeletal – goal is to move the skeleton

So, what about the tongue, pharynx, lips, soft palate that are not responsible for moving the skeleton?
Muscle Hydrostat

biological structure found in animals used to manipulate items (food) muscles with no skeletal support interdigitated muscle orientation deforms, many trajectories

What is striated muscle?

muscle hydrostats
tongue trunk tentacle

Part 1 Outline

Terminology Cranial Nerves and Muscle Swallowing Anatomy & Physiology Traditional Swallowing Treatment Heightened Stimulation & Swallowing Concepts in Neurophysiology
Structures

- Muscles, structures, muscle groups?
- Structure: tongue
- Muscles: intrinsic and extrinsic
- Muscles groups: suprathyroid, submental, floor of mouth, submandibular

Anatomical Regions of Head & Neck

- Nasopharynx
- Oropharynx
- Hypopharynx

May include structures or spaces

Vallecula

Pyriform sinuses

Valleculae pyriforms

http://www.meddean.luc.edu/lumen.meded Radiocurriculum/ENT/salena66a.jpg
Muscles of the Tongue

Intrinsic
- Superior Longitudinal
- Inferior Longitudinal
- Transverse
- Vertical

Extrinsic
- Genioglossus
- Styloglossus
- Palatoglossus
- Hyoglossus

Structures

TONGUE (intrinsic and extrinsic):
- Chewing – bolus manipulation and transport through oral cavity to pharynx
- Swallowing – swallowing initiation
- Motor - CN XII (hypoglossal)
- Sensory (general) – CNV anterior 2/3; CNIX posterior 1/3
- Sensory (taste) – CN VII – anterior 2/3; CN IX posterior 1/3

PHARYNX:
- Superior
- Middle
- Inferior
- Squeeze bolus downward
- Motor and sensory – CN IX & X
- Pharyngeal plexus
UPPER ESOPHAGEAL SPHINCTER (UES):

- Pharyngo-esophageal junction or segment
- CP - Primary muscle of UES
- Inferior IPC and superior cuff of the esophageal muscle contribute
- Attached to cricoid cartilage

UES Summary

- Moves with cricoid
- Laryngeal elevation plays a roll in opening the UES
- CP is tonically active, relaxes to open
LARYNX: Forms the superior terminal of the trachea. Principal biological function is protection of the lower respiratory tract (coughing, closure during swallowing).

Cartilaginous structure of the larynx. Suspended from the hyoid bone.

Extrinsic Laryngeal Muscles [Anterior View]

- Anterior Belly of the Digastric
- Mylohyoid
- Omohyoid & Sternohyoid
- Thyrohyoid
- Geniohyoid
Suprahyoid Muscles
(submental OR submandibular)
• Mylohyoid
• Ant. Belly of Digastric
• Geniohyoid

Infrahyoid Muscles
• Omohyoid
• Sternohyoid
• Sternothyroid

Thyrohyoid Muscle

The true and false vocal folds close the larynx intrinsically during swallowing.

But this is the last line of defense for airway protection during swallowing.

Intrinsic closure is neuromuscular.
How does the epiglottis flip? Is it neuromuscular or biomechanical or both?

How can movement occur?

**Neuromuscular**
A nerve innervates a muscle, causing the fibers that it controls to contract.

**Biomechanical**
Movement that can occur due to impinging forces from another structure

Biomechanical
Laryngeal opening (vestibule) is protected

Logemann et al 1992
“Closure mechanisms of the laryngeal vestibule”
Is the epiglottis necessary?

Epiglottis is not essential for successful swallowing in humans

Leder SB, Burrell MI, Van Daele, DJ

Abstract
We describe the effect of isolated epiglottectomy on swallowing success in a case series of 3 adult human subjects with isolated epiglottectomy due to trauma, surgery, or cancerous erosion. The patients were 42, 51, and 70 years of age, and swallowing was analyzed objectively with videofluoroscopy. All subjects exhibited successful swallowing with all food types: thin liquid, puree, and solid food. Specifically, the patient with traumatic epiglottectomy exhibited rapid swallowing success, the patient with surgical epiglottectomy exhibited a short period of dysphagia due to postoperative edema, followed by swallowing success, and the patient with epiglottectomy due to cancerous erosion of the entire epiglottis exhibited long-term adaptation, with successful swallowing maintained. We conclude that the epiglottis is not essential for successful swallowing in humans, because individuals can readily adapt to isolated epiglottectomy and avoid tracheal aspiration.
Adaptation in the presence of acute pathophysiology does not exclude importance of structures posterior glossectomy?

Structures

Sequence of activity during swallowing

Doty & Roena 1956 (in dog)

Triggering Pharyngeal Swallowing

• Important given the planes of the cavities
• Oral horizontal (time to prepare bolus)
• Pharyngeal vertical (gravity=danger)
• Critical area – increased sensory region to trigger patterned, automatic neuromuscular events
Summary of Swallowing A&P

Swallowing is a complex neuromuscular phenomenon comprised of voluntary and involuntary sensory and motor events that are necessary for safe bolus travel from mouth to stomach.
Part 1 Outline

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Therapy Categories

- Medical (i.e. drugs)
- Surgical (i.e. resections)
- Behavioral

Traditional Swallowing Treatments

- Compensatory
- Rehabilitative
- Behavioral
Compensatory Strategies
Short term adjustments to facilitate improved swallowing function
Can alter rheology (bolus flow)
Alter physiology?
Goal: compensate for problem

Rehabilitation
Goal: To restore functional swallowing
Systematic application of techniques
Often challenges abilities to encourage learning and improvement
Produce long-term improvement beyond the treatment period that generalizes to functional swallowing contexts

Postural Adjustments

Side lying (stronger side down)
Unilateral pharyngeal deficit slows bolus, directs strong hemipharynx, emphasizes pharyngeal contraction, less aspiration
Head extension (Chin Up)
Oral resection; lingual paresis propel bolus mouth-pharynx widens oropharynx; PES pressure better oral transit & clearance
Head flexion (Chin Tuck)
Deficits airway protection during swallow improves airway protection, vestibule closure; narrow oropharynx reduced aspiration
Head turn unilateral pharyngeal deficit post-swallow residue; aspiration occlude weak side; PES pressure residue; risk of aspiration
Postural Adjustments

<table>
<thead>
<tr>
<th>Technique</th>
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<td>head extension (Chin Up)</td>
<td>oral resection; lingual pharynx; propel bolus mouth-pharynx</td>
<td>widens oropharynx; PES pressure</td>
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Head Up

Postural Adjustments

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Chin tuck view from above

Chin Tuck

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<td>Head extension (Chin up)</td>
<td>Oral resection; liquid swallow</td>
<td>Proper bolus mouthpharynx</td>
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<td>Better oral transit &amp; clearance</td>
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<tr>
<td>Head flexion (Chin Tuck)</td>
<td>Deficit airway protection during swallow</td>
<td>Improves airway protection; vestibule closure; narrow oropharynx</td>
<td>Reduced aspiration</td>
<td>novice weak side; PES pressure; risk of aspiration</td>
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**Head Rotation**

Right Head Turn

Left Head Turn

**Swallowing Maneuvers:**

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<td>glottal closure</td>
<td>less aspiration, more hyoid elevation</td>
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Effortful: reduce base of tongue movement & pressure, increase lingual force on bolus tongue-palate pressure, longer swallow duration, less residue.
Airway Protection

Breath Hold

Effortful Breath Hold

Swallowing Maneuvers:

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<td>supradiaphragmatic</td>
<td>aspiration before, during swallow</td>
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<td>glottal closure</td>
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<tr>
<td>Mendelsohn</td>
<td>reduced hyo-laryngeal movement</td>
<td>increase hyo-laryngeal movement</td>
<td>longer, greater hyo-laryngeal movement</td>
<td>less aspiration, more hyoid elevation</td>
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Videofluoroscopy

change kinematics
**Maneuvres Summary:**

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<td>reduce base of tongue movement &amp; pressure</td>
<td>longer, greater hyoid laryngeal movement, less residue, more hyoid elevation</td>
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<tr>
<td>Effortful</td>
<td></td>
<td>increase lingual force on bolus, tongue-palate pressure</td>
<td>longer swallow duration, less residue</td>
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**Electromyography (EMG)**

*submental*
Thickening Liquids
(references in upcoming sections)
More viscosity slows bolus down
Impacts affect swallow physiology
(strength?)
More viscosity can reduce aspiration

Tactile Thermal Application
Stroke oropharyngeal regions (anterior faucial pillars) with a stimulus. The stimulus may be cold or have taste.
Inconsistently shown to reduce swallow delay
(Sciortino et al 2003)
Increases cortical representation of swallow
(Teismann et al 2009)

Biofeedback
(Langhorne et al 2009, Lancet Neurol)
Useful adjunct to help motor learning of novel or difficult motor patterns
Implemented to teach: relaxation, strengthening & coordination activities
Shown to enhance rate of motor learning by monitoring & displaying muscle activity
Part 1 Outline

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Heightened Stimulation & Swallowing
Concepts in Neurophysiology

Does heightened stimulation alter swallowing??
If so, why and how?

Sensory input may affect the threshold to induce swallowing differently

Steele & Miller 2010
Swallowing can be modulated by input

- Salivation
- Taste
- Temperature
- Volume
- Electrical Stimulation
-aine
- Airpuff
- Carbonation
- Tongue
- pharynx larynx

bolus sensed by the PNS
bolus sensed by the PNS
sensory information sent to CNS

movement command sent from CNS to various swallowing structures

With heightened stimulation (i.e. sour bolus)
enhanced bolus sensed by the PNS
How does the research literature differentiate the effects of various forms of stimulation on swallowing?

Most frequently studied form: bolus modifications effects on swallowing
Types of bolus modification:

- Taste
- Temperature
- Volume
- Consistency
- Chemesthesis
- Mode of Delivery
- Combinations
- Anesthesia

Taste vs Flavor

- Sour
- Umami
- Bitter
- Salty
- Sweet

(pure) taste
Taste vs Flavor

- Sour
- Umami
- Bitter
- Salty
- Sweet

(pure) taste + flavor

retronasal smell

Bolus Modification

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Sour

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- No difference in delays (Palmer 2005)
- No difference in hyo-laryngeal timing or peak range of movement (Humbert 2012)
- Shorter delays before swallowing onset (Ding 2003)
- Longer swallow duration (Handy 2003; Chee 2005)
- Shorter swallow duration (Leow 2007)
- More strength, pressure (Palmer 2005; Pelletier 2006; Leow 2007)
- Improved physiology and/or reduce aspiration (Logemann 1996; Kogel 2003; Pelletier 2001)
Sweet

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<td>(none)</td>
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Shorter delays before swallowing onset (Ding 2003)
Longer swallow duration (Chee 2005)
Shorter swallow duration (Leow 2007)
More lingual pressure (Pelletier 2006)

Salty

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Longer swallow duration (Ding 2003; Chee 2005)
More lingual pressure (Pelletier 2006)

Taste Effects Summary

Sour – Mixed physiology effects; reduced patient aspiration
Sweet – Timing and lingual pressure changes
Salty – Timing and lingual pressure changes
Temperature

Temperature (primarily cold stimuli)

Unchanged
- Pharyngeal peristalsis amplitude, duration, or velocity (Shaker 1993)
- Swallow trigger (Shaker 1994; Ali 1996)
- Swallowing speed (Bove 1998)

Changed
- Longer pharyngeal response and laryngeal elevation durations (Bisch 1994)
- Increased swallowing latency and frequency (Kaatzke-McDonald 1996)
- Shorter swallow onset delays (Selcuk 2007)

Patients
dysphagic, neurologically impaired patients exhibited very few significant effects of temperature on swallowing disorders or swallow measures. (Bisch 1994).
Temperature

Overall assessment of temperature effects: mixed
need more studies on hot temperatures
need more patient studies

Volume

hypo-laryngeal movements

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<tr>
<td>duration of vocal fold closure (Shaker 1993)</td>
<td>interarytenoids activity increased in duration between saliva and 10-ml (Partman 1999)</td>
</tr>
<tr>
<td>laryngeal closure with increasing volume (Maddock 1993)</td>
<td>arytenoid to epiglottis contact time increased with bolus volume (Logemann 1992)</td>
</tr>
<tr>
<td>submental or infrahyoid activity or hyoid movement (Dantas 1990)</td>
<td>duration of hyoid elevation increased with larger bolus (Humbert 2012)</td>
</tr>
<tr>
<td>laryngeal vestibule closure in healthy or in stroke with or without aspiration (Commen 2011)</td>
<td>peak hyoid elevation increased with larger bolus (Humbert 2012; Cit-Fishman 2002, Jacob 1989; Budda 1988)</td>
</tr>
<tr>
<td>hyoid excursion with large bolus in PD patients or healthy adults (Wintzen 1994)</td>
<td></td>
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</table>
### Volume

<table>
<thead>
<tr>
<th><strong>Bolus Timing</strong></th>
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<tr>
<td>bolus transit time through the mouth and pharynx (Dantas 1990)</td>
</tr>
<tr>
<td>bolus head flow with increasing volume (Maddock 1993)</td>
</tr>
<tr>
<td><strong>Changed</strong></td>
</tr>
<tr>
<td>decreased swallow delay with more volume in neurologically impaired (Bisch 1994)</td>
</tr>
<tr>
<td>bolus transit time through oral and pharyngeal cavities decreased, (Rademaker 1998)</td>
</tr>
<tr>
<td>increased the duration of barium flow through the UES (Dantas 1990)</td>
</tr>
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### Volume

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<tr>
<th><strong>Pharynx, velum, and UES</strong></th>
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<td>pharyngeal peristalsis amplitude, duration, or velocity (Shaker 1993)</td>
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<td>pharyngeal delay time (healthy) (Lazarus 1993)</td>
</tr>
<tr>
<td>pharyngeal pressure differences (Gumbley 2008)</td>
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<tr>
<td><strong>Changed</strong></td>
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<tr>
<td>duration of velopharyngeal pressure, UES opening increased with larger bolus (Hoffman 2010; Gumbley 2008)</td>
</tr>
<tr>
<td>duration of CP opening and tongue base to posterior pharyngeal wall contact increased with larger bolus (Lazarus 1993)</td>
</tr>
<tr>
<td>pharyngeal delay time diminished in stroke patients with larger bolus (Lazarus 1993)</td>
</tr>
<tr>
<td>pharyngeal delay decreased, while CP opening and VP closure increased with a larger bolus (Rademaker 1998)</td>
</tr>
<tr>
<td>more UES opening with larger bolus (Jacob 1989; Kahrilas 1988)</td>
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### Volume

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<tr>
<th><strong>Aspiration patients versus non-aspirating patients</strong></th>
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<tr>
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<tr>
<td>no significant difference between 5ml and 10ml for hyoid movement between aspirating and non-aspirating stroke patients (Kim 2010)</td>
</tr>
</tbody>
</table>
Volume

Overall assessment of volume effects:
- Hyo-larynx and bolus movement have mixed results
- Pharynx, UES, velum mostly changed
- Need more studies on aspiration
- Need more patient studies

Consistency/Viscosity

Safer swallows with 2% milk and whole milk than for skim milk and water (Butler 2011)

Swallow delay or LVC (healthy and stroke) (Oommen 2011)

Longer CP opening on paste swallows than water (Lazarus 1993)

Delayed oral and pharyngeal bolus transit, increased pharyngeal peristaltic waves, UES opening, and extrinsic laryngeal muscle activity with more viscosity (Dantas 1990)

Tongue movement across thin to honey-thick consistency range (Steele 2004)

Unchanged
- Swallow delay or LVC (healthy and stroke) (Oommen 2011)
- Tongue movement across thin to honey-thick consistency range (Steele 2004)
- CP opening on paste compared to water (patients) (Lazarus 1993)
- Pharyngeal transit time (patients) (Troche 2008)

Changed
- Safer swallows with 2% milk and whole milk than for skim milk and water (Butler 2011)
- Longer CP opening on paste swallows than water (Lazarus 1993)
- Delayed oral and pharyngeal bolus transit, increased pharyngeal peristaltic waves, UES opening, and extrinsic laryngeal muscle activity with more viscosity (Dantas 1990)
- Longer oral transit time, more tongue pumps, safer swallowing scores with more viscosity (patients) (Troche 2008)
- Decreased pharyngeal delay with more viscosity (patients) (Bisch 1994)
Consistency/Viscosity

Overall assessment of viscosity effects: mixed
need more patient studies

Chemesthesia

ethanol
Capsaicin (pepper)
carbonation

"Chemesthesia is a chemically stimulated sensation of irritation mediated by the trigeminal nerve that is elicited by such stimuli as carbonation and high concentrations of salt or citric acid. It is neither a taste nor smell. It is a somatosensory perception that adds to the flavor experience. For example, it is responsible for the perception of hotness from a chili pepper or coolness of menthol".

Plonk et al 2011
Carbonated thin liquid significantly decreased penetration and aspiration (Sdravou 2011).

Durations of tongue movements with chemesthetic-taste stimulus of high citric acid compared with water (Steele 2012).

Lingual pressure durations were greater for carbonation than for water (Krival 2011).

Carbonated thin liquid had no significant effect on oral or pharyngeal transit times or pharyngeal response (Sdravou 2011).

Overall assessment of chemesthetic effects: mixed.

Mode of Delivery:
## Mode of Delivery

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</tr>
</thead>
<tbody>
<tr>
<td>Penetration and aspiration with</td>
<td>More penetration or aspiration with straw than cup</td>
<td>More penetration or aspiration during sequential swallowing than single swallows in acute stroke and healthy groups</td>
</tr>
<tr>
<td>(cup vs straw)</td>
<td>(Butler 2011)</td>
<td>(Murguia 2009)</td>
</tr>
<tr>
<td>Swallow kinematics</td>
<td>(direct pharyngeal liquid delivery) (Shaker 1994)</td>
<td>Most penetration seen with sequential swallowing compared to single swallows (Tsushima 2009)</td>
</tr>
<tr>
<td>(direct pharyngeal liquid delivery)</td>
<td>(Humbert 2010)</td>
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</tr>
<tr>
<td>Hyo-laryngeal kinematics</td>
<td></td>
<td></td>
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<tr>
<td>(direct pharyngeal liquid delivery)</td>
<td>(Humbert 2010)</td>
<td></td>
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</tbody>
</table>

## Mode of Delivery

**Overall assessment of mode of delivery effects:**
- cup versus straw mixed
- direct to pharynx unchanged
- sequential versus single changed

## Combinations

<table>
<thead>
<tr>
<th>Taste</th>
<th>Mode of delivery</th>
<th>Carbonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT</td>
<td>+</td>
<td>= ??</td>
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</table>
### Combinations

<table>
<thead>
<tr>
<th>Unchanged</th>
<th>Changed</th>
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<td>(more)</td>
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</table>

- Cold + sour reduces pharyngeal transit time most in stroke (Cola 2010)
- Mechanical stimulus + cold + taste had shortest swallow delay compared to no stimulation or individual forms of stimuli (Sciortino 2003)
- Cold + citrus slowed swallow speed and decreased amount swallowed (healthy and stroke) (Hamdy 2003)

#### Overall assessment of combination effects:
Greater changes with combinations of stimuli types

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### Texture

- [Image of various textures]
### Anesthesia

**Swallowing not inhibited by topical anesthesia to the tonsillar pillars** (Ali et al 1996).

- Pharyngeal anesthesia abolished reflex pharyngeal swallow in healthy, non-smokers resulting in laryngeal spillage (Dua et al 2011).
- Oral anesthesia immediately reduced swallowing speed and time between swallows, but not amount swallowed (Chee et al 2005).
- Laryngeal nerve block caused significantly more premature spillage, pharyngeal residue, and laryngeal penetration with all consistencies, and a higher incidence of tracheal aspiration with liquid (Sulica et al 2002).

<table>
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<td>al 2002)</td>
</tr>
</tbody>
</table>
Anesthesia

5 of 12 subjects demonstrated the clinical signs of laryngeal aspiration at the earlier period of the topical oropharyngeal anesthesia (Ertekin et al 2000).

After anesthesia in both surface and blocked groups, deglutitive tongue movement slowed and bolus movement was delayed (Fujiki et al 2001).

Swallowing Physiology: Part 1

Summary

Use and understand the correct terminology
Skeletal muscle and muscle hydrostats are different
Peripheral swallowing system is complicated, therefore requires in-depth understanding
Traditional swallowing behavioral therapies are often categorized as compensatory or rehabilitative
Bolus effects on swallowing have mixed effects, based on the research literature